STABILITY ANALYSIS UTILIZING ENTRAINMENT TECHNIQUES

A. C. KRANZ

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by
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PREFACE

This paper is an attempt to determine an objective quantitative method of forecasting thunderstorms and lesser convective activity by evaluation of radiosonde data employing techniques of entrainment. The work was done at the U. S. Naval Postgraduate School, Monterey, California, as a partial requirement for the degree of Master of Science in Aerology.

The author wishes to acknowledge the help and guidance of Associate Professor G. J. Haltiner, Department of Aerology, U. S. Naval Postgraduate School, Monterey, California.

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I. INTRODUCTION

Stommel [7], in 1946, made the assumption that the ascending cloud draws in air from the environment and mixes with the cloud substance, thus modifying the mechanical and thermodynamic character of the cloud. One important effect of this entrainment is that the lapse rate within the cloud is not wet-adiabatic as previous theories predict. Measurements of trade wind cumulus were obtained near San Juan and provided an excellent test for this hypothesis. The existence of entrainment was also verified from computations of horizontal divergence made by Byers and Hull [3] from data obtained during the thunderstorm project [3].

Present theories of convection and resulting stability criteria make no provision for this entrainment process. The purpose here is to utilize the entrainment process as developed by Austin [1] and later verified by Riehl [6] in an effort to provide a more accurate stability criteria for forecasting convective phenomena and, moreover, to test the criteria statistically.

Austin [1], in 1948, expressed the idea that entrainment is necessary to satisfy continuity. In his study, he assumed the clouds were formed as the result of heating at the ground, that the rising cloud mixes with the environment air. In addition, when mixing occurs, the nonsaturated environment becomes saturated by the wet-bulb process and, finally, the lapse rate of temperature within the cloud is obtained by the computed values of the temperature of the cloud top as it grows upward from the condensation level.

Houghton and Cramer [4] present a more complete theory of entrainment in accelerated vertical motion but indicate no methods adaptable for use in forecasting instability phenomena.

II. PROCEDURES AND RESULTS

Atlanta was chosen as the radiosonde station in this work because of the frequent thunderstorms occurring due to surface heating. The 1000 local time (1500Z) soundings were used, and the data was taken from the Daily Upper Air Bulletin for May and July 1951 and July 1950. The pseudo adiabatic chart was used for the computations. Surface data was obtained from the file of weather maps at the Postgraduate School and the Station Meteorological Summary of Atlanta.

As the moisture content of the air is significantly related to convection, a study of the change in mixing ratio from 1000 EST sounding to the 2200 EST sounding was made; results of which are shown in Figure 1. This was done in an attempt to determine a value of mixing ratio to add to the morning sounding and thereby approximate afternoon conditions. As the times of the soundings corresponded approximately to the times of minimum mixing ratio this was not possible. Noteworthy, however, is the abrupt decrease of mixing ratio and corresponding absence of convective activity during the period July 5-10, 1951. As suggested in the Handbook of Meteorology [2] , an average value of two grams per kilogram was added to the morning sounding. This value is representative of a maritime tropical air mass present over Atlanta during the time under study.

Various values of entrainment rates have been measured during the thunderstorm project [3] and by Stommel [7]. On the basis of this data it was decided to use an average rate of 100% per 300 millibars, that is, doubling the mass in an ascent of 300 millibars.

In applying these methods it would be necessary to forecast maximum temperature. The purpose here is primarily to test the effects of entrainment and therefore, maximum temperature was eliminated as a variable by using the available data.

The assumption of heating to the condensation level was made, and accordingly, the intersection of the surface mixing ratio line and the dry adiabat through the maximum temperature was considered the condensation level.

Two methods of entrainment were used to determine which method lent itself more readily to analysis of radiosonde soundings. Progressive entrainment no doubt more closely approximates reality. However, the single ascension adiabat method provides the same qualitative effect and larger areas between environment and ascent curves result. The two methods are illustrated in Figures 3 and 4.

The change in kinetic energy is directly proportional to the "positive" and "negative" areas between the environment curve and the curve representing the rising air. Measurement of these areas is a tedious, time consuming task and, therefore, an alternate procedure was used in the test. The cumulative temperature difference between

the two curves is, in effect, a direct measure of the "positive" and "negative" areas. This difference is readily measured and any loss in accuracy would be slight.

For a convective index the observed weather phenomena was assigned values as follows:

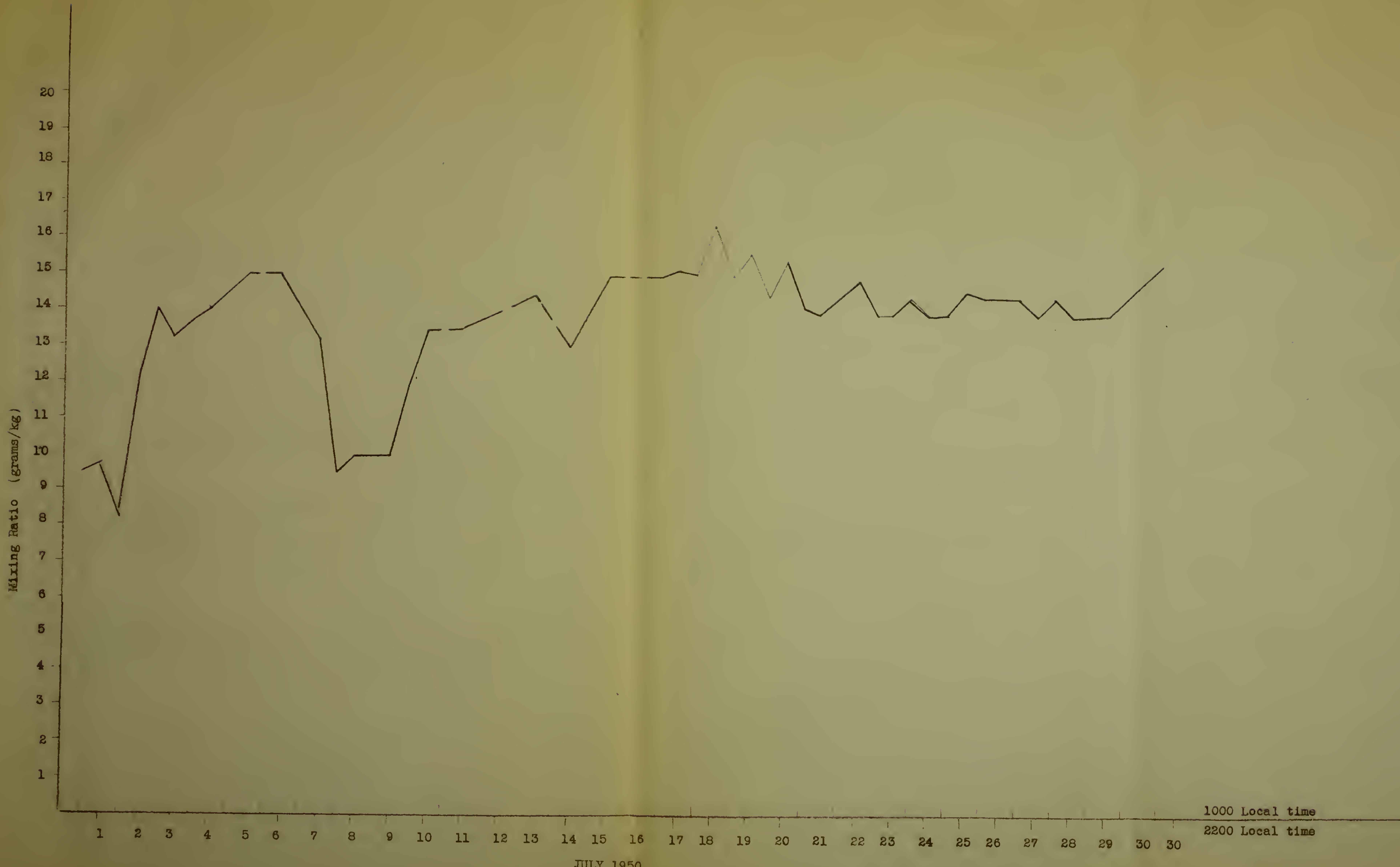
Thunderstorm	10
Cumulo-nimbus with showers	8
Cumulo-nimbus	7
Cumulus congestis	6
Cumulus of fair weather	5
Strato cumulus vesperalis	4
Strato cumulus	2
Alto cumulus	2
Stratus, clear	0

The soundings of July 1951 were analyzed using progressive entrainment every hundred millibars from the condensation level to 500 millibars. The cumulative temperature difference between the environment and the rising cloud was then divided by the number of entrainment levels and correlated with the convective index. A linear correlation coefficient of <u>0.20</u> resulted. The July 1950 soundings were analyzed by the single ascension adiabat method in a similar manner and a linear correlation coefficient of <u>0.59</u> resulted.

Of course, since different sets of data were employed, no real comparison of the correlation coefficients can be made. However, the progressive entrainment method produces smaller temperature differences which are more difficult to measure. In view of this, the May 1951 soundings were analyzed by the single ascension adiabat method and grouped with the data of July 1950. A linear correlation coefficient of 0.72 resulted. A scatter diagram was prepared and a regression line determined (Figure 5.).

As an additional study, the temperature difference between the environment and the rising cloud was measured at the 700 millibar and the 500 millibar levels and correlated with the convective index. The 700 millibar level showed a linear correlation coefficient of 0.55, and the correlation coefficient for the 500 millibar level was 0.49. There is no significant difference between these levels, both of which are inferior to cumulative temperature method.

It is believed that this method can be utilized to good advantage at any station as an aid in forecasting convective activity. A more complete study of the daily moisture change would probably result in greater success.



Mixing Ratio (grams/kg)
20
19
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15
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9
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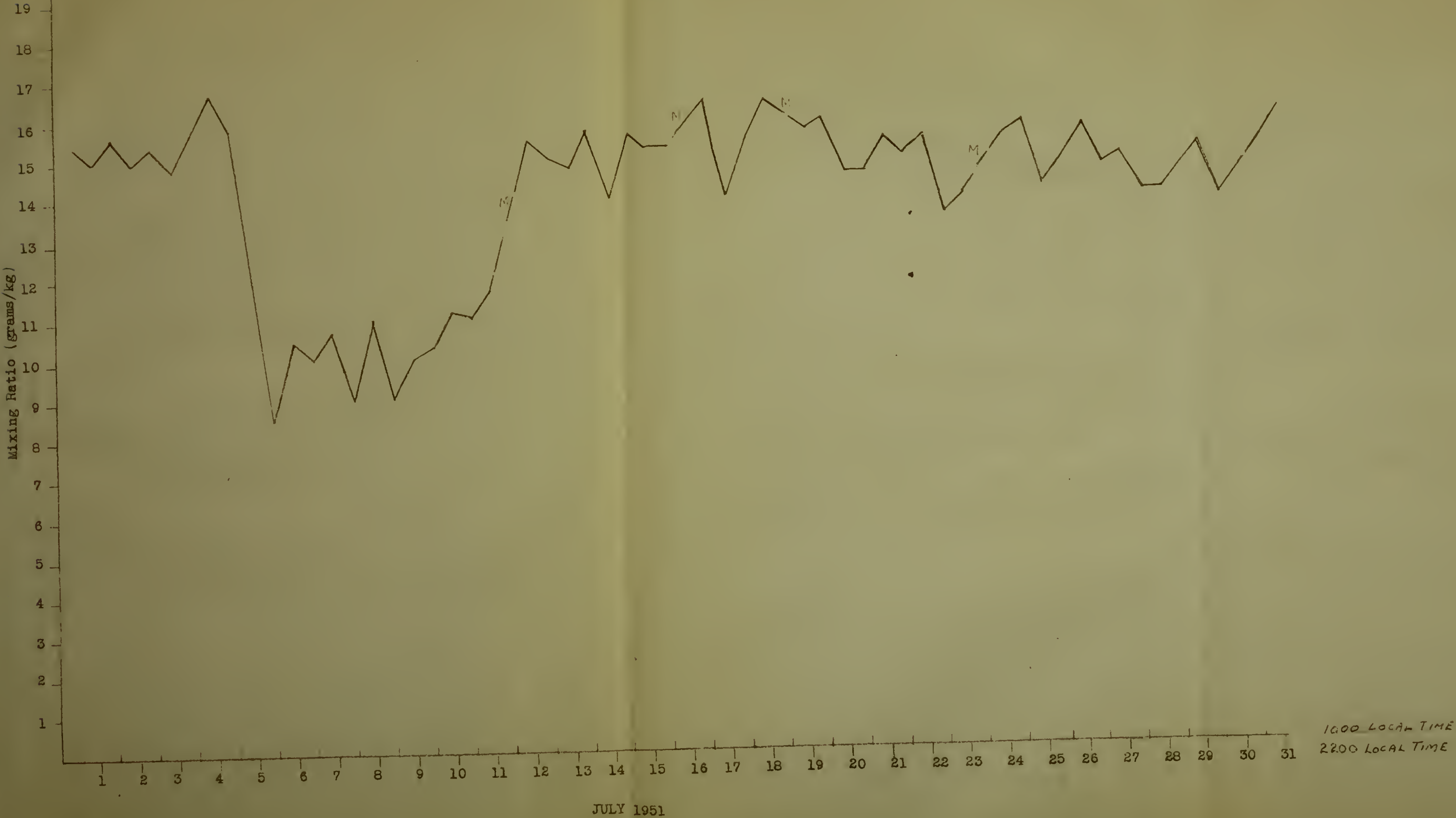
JULY 1950


Mixing Ratio (grams/kg)
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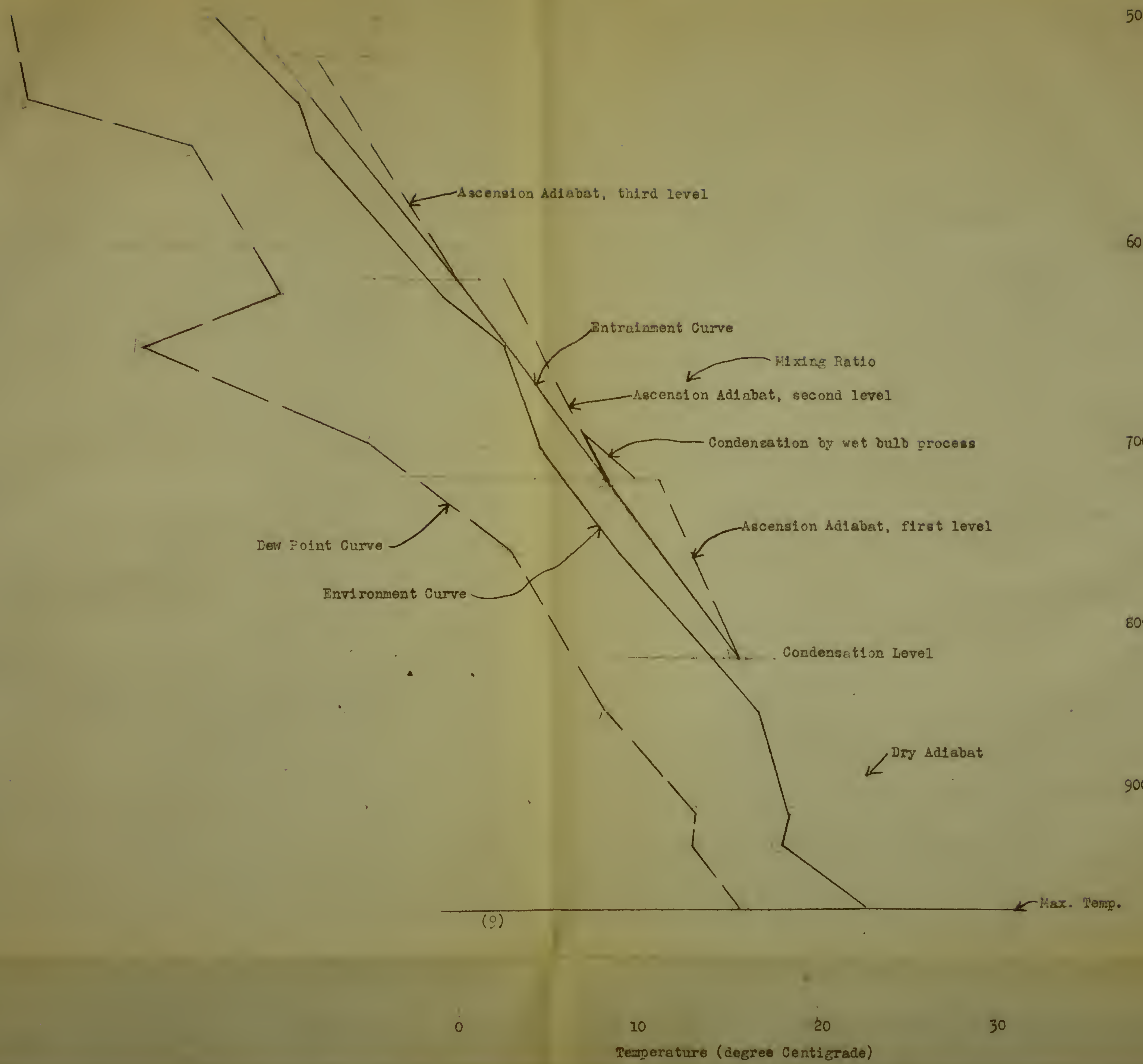
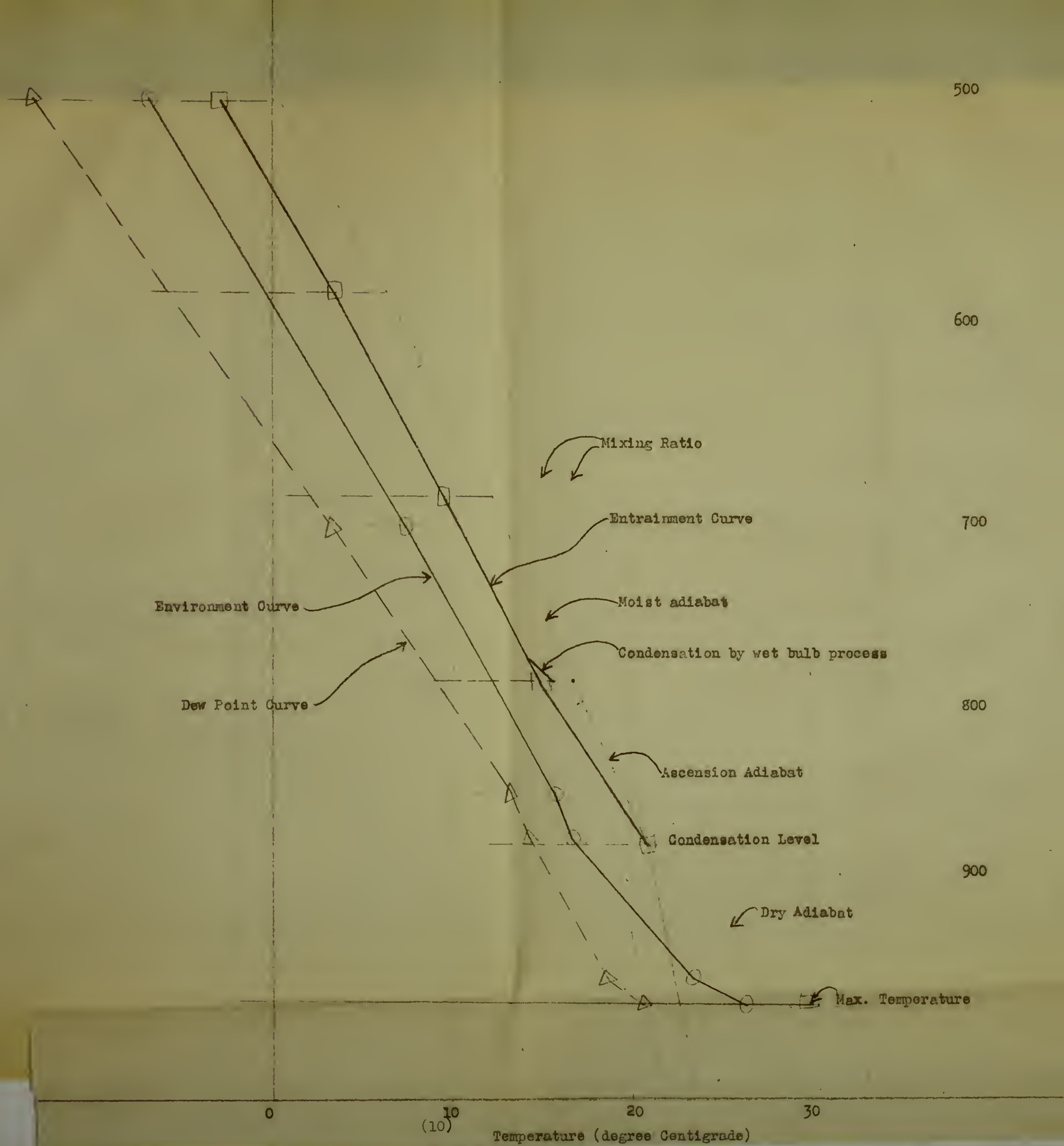
JULY 1951


500
600
700
800
900
Ascension Adiabat, third level
Entrainment Curve
Mixing Ratio
Ascension Adiabat, second level
Condensation by wet bulb process
Ascension Adiabat, first level
Dew Point Curve
Environment Curve
Condensation Level
Dry Adiabat
Max. Temp.
0
10
20
30
Temperature (degree Centigrade)



500
600
700
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Mixing Ratio
Entrainment Curve
Environment Curve
Moist adiabat
Condensation by wet bulb process
Dew Point Curve
Ascension Adiabat
Condensation Level
Dry Adiabat
Max. Temperature
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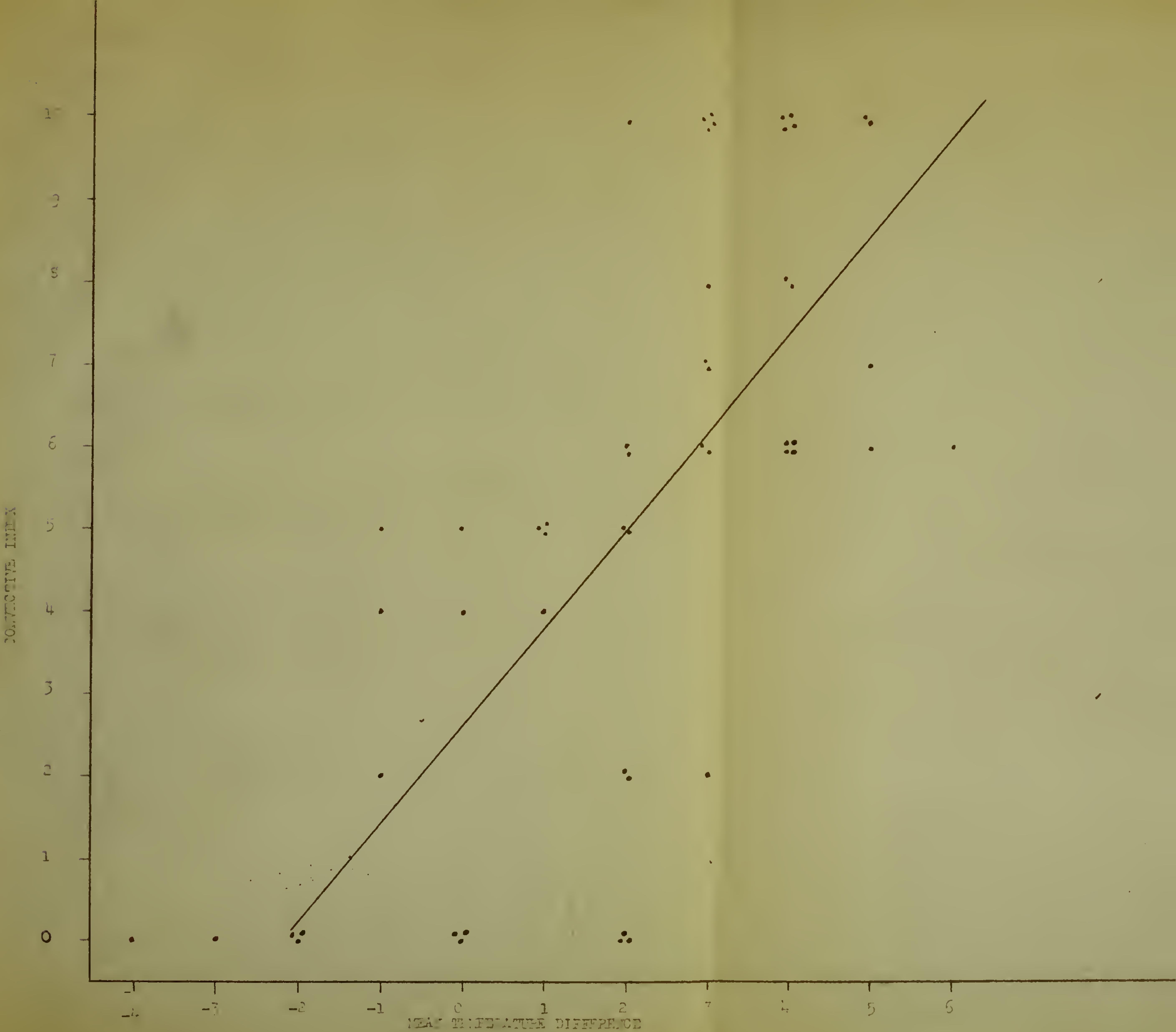
Temperature (degree Centigrade)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2
5
6

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